Evaluation of the accuracy of image manipulation in the P3Dental™ software for guided implantodontic surgeries

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ABSTRACT

Purpose: To collect and analyze data to determine the level of precision of the virtual values provided by P3Dental™ image manipulation software in comparison with real values measured using a digital pachymeter in polyurethane mandibles. Materials and methods: Five polyurethane mandibles were sectioned and drilled, providing a total of 120 samples for study, and then scanned with cone beam computed tomography. The images obtained were manipulated using the P3Dental™ software package and the resulting values were analyzed in comparison to the real values measured using a digital pachymeter with the aid of IBM® SPSS® database software. Results: Statistical analysis showed that there were significant differences (P=0.01) between the virtual values measured using P3Dental™ software and the real values measured with the digital pachymeter, which had mean ± standard deviation of 8.15 ± 1.01mm and 7.89 ± 0.90mm respectively. Conclusions: In view of the statistically significant differences observed, dental surgeons should be aware that the guided surgery technique must be employed with care right from the outset since small errors of use are cumulative, increasing the likelihood of distortion between the ideal (virtual) and final (real) positions of the implants.

Keywords: cone beam computed tomography, Surgery, Computer-Assisted, Dental Implants.

Avaliação da precisão da manipulação de imagens no software P3Dental™ para cirurgias guiadas em implantodontia

RESUMO

Objetivo: Coletar e analisar dados para determinar o nível de precisão dos valores virtuais fornecidos pelo software de manipulação de imagens P3Dental™ em comparação com valores reais medidos usando um paquímetro digital em mandíbulas de poliuretano. Materiais e métodos: Cinco

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mandíbulas de poliuretano foram seccionadas e perfuradas, fornecendo um total de 120 amostras para estudo, e então escaneadas com tomografia computadorizada de feixe cônico. As imagens obtidas foram manipuladas utilizando o pacote de software P3Dental™ e os valores resultantes foram analisados em comparação com os valores reais medidos usando um paquímetro digital com o auxílio do software de banco de dados IBM® SPSS®. Resultados: A análise estatística mostrou que houve diferenças significativas (P = 0,01) entre os valores virtuais medidos com o software P3Dental™ e os valores reais medidos com o paquímetro digital, que teve média ± desvio padrão de 8,15 ± 1,01mm e 7,89 ± 0,90mm respectivamente. Conclusões: Tendo em vista as diferenças estatisticamente significantes, os cirurgiões dentistas devem estar cientes de que a técnica da cirurgia guiada deve ser empregada desde o início com cuidado, já que pequenos erros de sua utilização são cumulativos, aumentando a probabilidade de distorção entre as posições ideal (virtual) e final (real) dos implantes.

Palavras-chave: Tomografia computadorizada de feixe cônico. Cirurgia assistida por computador. Implantes dentários.

INTRODUCTION

Over recent years, the art and science of fitting dental implants and prosthetic therapies have made impressive progress in substitution of lost teeth. Oral rehabilitation using implants is now a well established and widely employed procedure all over the world (1-2).

Implant companies have made a large number of new technologies available to dental surgeons, designed to simplify surgical technique and reduce total treatment time (3-4).

Application of computed tomography and computer software to treatment has increased significantly over time in the field of Implant Dentistry (5).

Computed tomography is considered a valuable tool that makes it possible to employ three-dimensional imaging to diagnose characteristics of bone structures, including density, volume and architecture, and also for identification of anatomic structures (such as the maxillary sinus and the mandibular canal) (6-9).

In general, the quality of computed tomography is dependent on slice thickness and the influence of artifacts. The thinner the slice, the higher the resolution of the image and the greater the accuracy of measurements of structures (7). However, it is known that there is a certain number of features of the scanning protocol (i.e., movements of the patient, image pixel saturation, and position of the mandible in relation to the computed tomography) that can affect the precision and quality of linear measurements made on cross-sectional images. These distortions can cause undesirable effects in implant surgery, most notably in terms of imprecision in implant positioning, resulting in unsatisfactory biological, biomechanical and esthetic effects (8).

Additionally, Implant Dentistry has developed into a faster and less invasive method for restoring lost dentition and producing more aesthetically pleasing results. Guided surgery is often recommended for procedures without flaps and for placement of implants when the quantity of bone is limited or in proximity to critical anatomic structures (10), reducing duration of surgery and accelerating treatment

(11). Notwithstanding, the treatment options in oral surgery are dependent on precise diagnostic imaging (12). Computer guided implant planning systems can considerably improve treatment quality, aiding in the process of transferring the patient's treatment plan to the operating setting (6,13).

There are many reports in the literature relating to measurement of the precision of transference of implant positions planned in software to the final positions of the implants in place after the surgical procedure (3). Even when planning is three-dimensional, positioning of the implants is merely "guided" on the computer screen. Additionally, the guide must be perfectly fitted and fixed to the fibromicous lining (3). Although a range of different planning software is available for virtual planning, it is important to identify a precise system for safely transferring the planning that has been performed virtually to the surgical setting (2,10).

The exactness of an image-guided procedure is defined by the deviation from the location or angle planned by comparison with the final result. When possible causes of error within the guided surgery technique are analyzed with respect to deviations from planning as detected in the final results, it is observed that these deviations reflect the sum of errors such as: problems with obtaining tomography data, incorrect positioning of the x-ray guide, the precision with which the metallic rings are placed in the guides, and fixing of the guide to the bone during surgery (14-15). It is of fundamental importance to become familiarized with the guided surgery system to minimize transoperative errors, since deviations from planned implant positions involves risks to patients and to rehabilitation quality, especially in flapless guided surgery. Therefore, the maximum observed deviation should be taken into account and used to determine a safety zone for performing a given procedure (14).

In view of the above, the objective of this study is to analyze the reliability for reproducing patient examinations using P3Dental™ image manipulation software (Protótipos 3D©, Porto Alegre, Brazil) for Implant Dentistry planning, when compared with the original anatomic specimens.

METHODOLOGY

For data acquisition, five polyurethane mandibles were identified (by number of mandible, section and side) and sectioned at four points in the region of the body of the mandible bilaterally (right and left), between the third molar and the mental foramen. Each section was drilled approximately in the center using a spherical bur at low rotation to simulate the mandibular canal.

After sectioning, CrNi™ orthodontic ligature wires (Dental Morelli Ltda©, Sorocaba, São Paulo, Brazil) with a thickness of 0.30mm were attached to each piece using super glue (Loctite Super Bonder precision™, Henkel Ltda.©, Düsseldorf, Germany), from the superior part of the bony crest to the superior point of the mandibular canal and from the inferior part of the mandibular canal to the inferior part of the basilar bone, on

the mesial and distal surfaces of each specimen. Each section was individually mounted on utility wax, placed at 90º to minimize any distortions, and then attached to an acrylic board for radiography. The acrylic board was positioned and fixed to the tomograph with masking tape (2314-C™, 3M©, Maplewood, Minnesota, United States) and the specimens were scanned using an OP300® imaging system (Instrumentarium Dental, Tuusula, Finland), positioning each plastic anatomic mandible in the centre of the visual field, using the luminous reference lines. The parameters used for image acquisition were: 90 kVp, 6.3 mA, voxel size of 0.12mm and a 6 x 8 cm FOV (Figures 1 and 2).

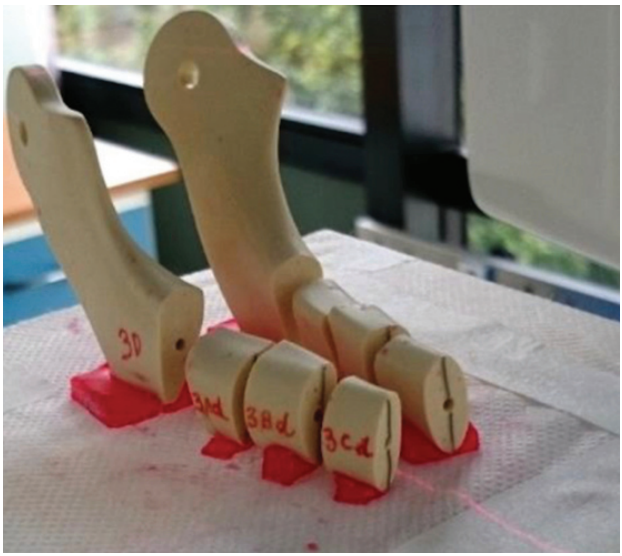

Figure 1. Polyurethane mandible mounted with utility wax onto an acrylic board for cone beam computed tomography (Cone-Beam), showing positioning, the sections with CrNi™ orthodontic ligature wires in place and the luminous reference tomography guide-lines.

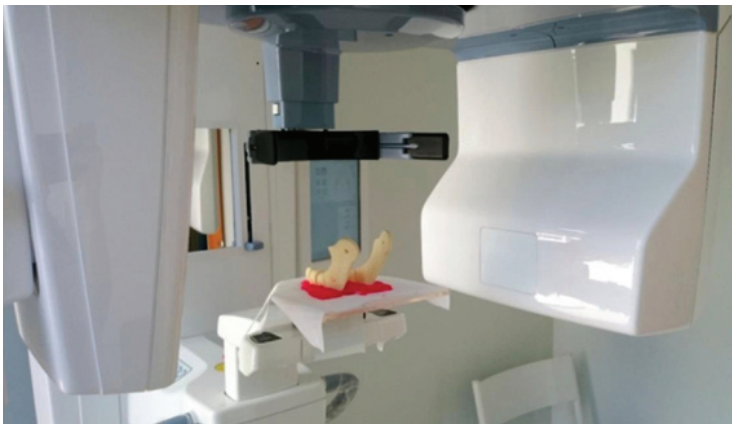

Figure 2. Conducting cone beam computed tomography.

The original data acquired were viewed as images in OnDemand3D™ software (Cybermed Inc., Korea, Asia) (Figure 3) and saved as files in DICOM format on removable storage media for viewing and analysis of the tomographs on P3Dental™ software (Protótipos 3D©, Porto Alegre, Brazil).

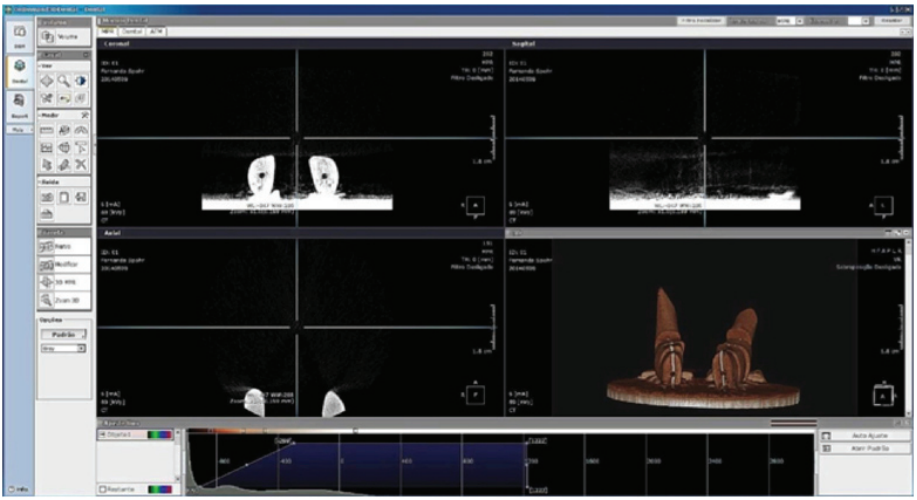

Figure 3. Image of mandible viewed with OnDemand 3D™ software.

The results of the tomography scans were loaded into the P3Dental™ image manipulation software (Figure 4), which was used to measure the CrNi™ orthodontic ligature wire from the lowest point of the base of the mandible to the lowest point of the mandibular canal and from the highest point of the crest of the alveolar process to the highest point of the mandibular canal. This procedure was conducted 3 times to obtain 3 measurements of each dimension, which were then used to calculate means. For each section of mandible it was necessary to add and manipulate points to the axial images over each radiopaque image of the CrNi™ orthodontic ligature wires to make it possible to completely view each wire in the software's panoramic images. This resulted in 360 measurements, 3 for each part analyzed, which were summed and divided by 3 to obtain a mean, totaling 24 (twenty-four) measurements per mandible and 120 (one hundred and twenty) virtual measurements for the entire study.

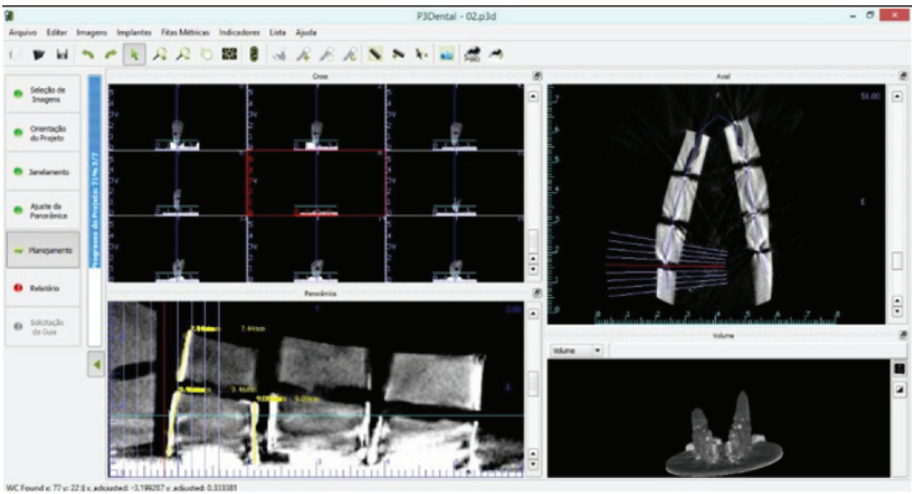

Figure 4. Three-dimensional image of a specimen being manipulated with P3Dental™ software to take virtual measurements.

Data were input to a spreadsheet using Excel™ 2013 (Microsoft© Office™, Redmond, Washington) and then the 120 (one hundred and twenty) measurements from P3Dental™ image manipulation software, were analyzed in comparison to 120 (one hundred and twenty) measurements of the CrNi™ orthodontic ligature wires that were obtained by measuring each original anatomic specimen using a Frankford Arsenal® digital pachymeter (Figure 5).

Figure 5. Taking a real measurement of one of the sections of mandible.

Statistical analysis was performed using the database software SPSS® Statistics version 19.0 (IBM®, Armonk, New York). Results are shown in tables and illustrated using graphs and results for continuous variables are expressed as minimum and maximum values, means and standard deviations. Student's t test for independent samples was used to compare measurements taken using the two different methods, both for overall comparison, and for the different sides (right and left) and for superior and inferior measurements separately. The Kolmogorov Smirnov test was used to assess normality of data.

RESULTS

As can be observed in Table 1, comparison of the 120 (one hundred and twenty) measurements taken with the Frankford Arsenal® digital pachymeter with the 120 (one hundred and twenty) means of the measurements made using P3Dental™ software shows that larger values resulted from measurements made using P3Dental™ software. For example, the minimum value for measurements made with the software was 5.86mm and the maximum value was 11.08 mm, in comparison with a minimum value of 5.62 mm and a maximum value of 10.08mm measured with the Frankford Arsenal® digital pachymeter.

Figure 6 illustrates that in 72 cases the measurement result using P3Dental™ software was larger than the measurement taken with the Frankford Arsenal® digital pachymeter. There was only one case, section 5CDSD, in which the measurements with the digital pachymeter and with P3Dental™ software returned the same result, which was 7.1 mm. In three cases, sections 1AMSE, 1CMIE and 3BMIDD, the difference between measurements with different equipment was 0.2 mm. The greatest differences were observed for sections 2ADID and 2BDID, for both of which the difference between measurements was 1.92 mm. The digital pachymeter measurement for section 2ADID was 8.81 mm, whereas the result using P3Dental™ software was 10.73 mm and the digital pachymeter value for 2BDID was 8.03 mm, compared to 9.95mm with P3Dental™ software. It can therefore be concluded that there was a statistically significant difference (P=0.03) when measurements made using P3Dental™ software were compared with measurements taken with a Frankford Arsenal® digital pachymeter.

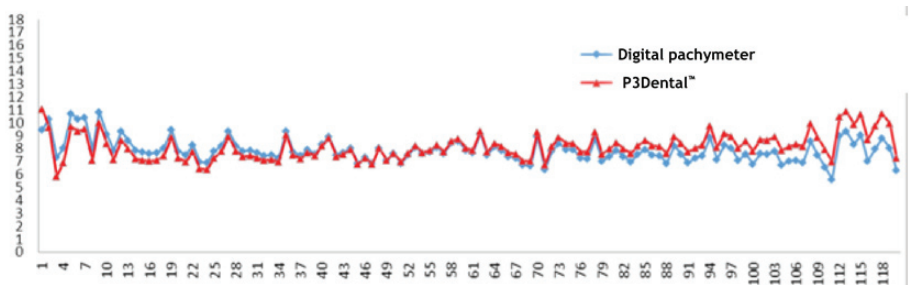

Figure 6. Distribution of measurements taken using a Frankford Arsenal® digital pachymeter and P3Dental™ image software for planning.

Comparisons were also made of the measurements from P3Dental™ software and with the Frankford Arsenal® digital pachymeter considering only right-side measurements and then only left-side measurements. Table 2 lists the results for right-side measurements with each type of equipment, showing that the mean with P3Dental™ software was 8.39mm while the mean with the digital pachymeter was 7.63mm. It can be observed that in fifty-three cases the measurements using P3Dental™ software were larger than the measurements taken with the Frankford Arsenal® digital pachymeter (Figure 7). It can therefore be concluded that there was a statistically significant difference (P=0.01) between the two sets of measurements.

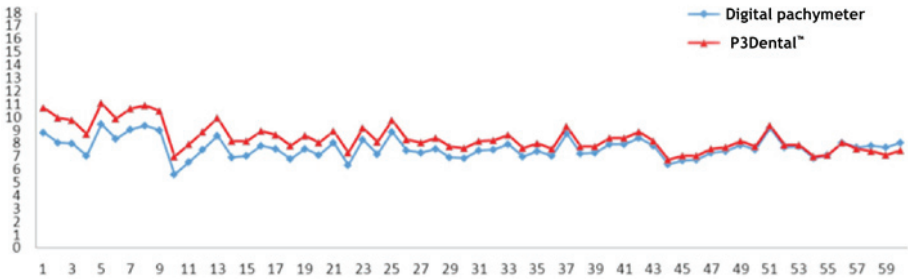

Figure 7. Distribution of right-side measurements.

It can be observed from Table 3 that for the left-side measurements the result is the inverse of that for the right side. The mean result for the Frankford Arsenal® pachymeter was 8.13mm, whereas the mean measurement with P3Dental™ software was 7.91 mm. Figure 8 illustrates that in forty-two cases the measurements taken with the Frankford Arsenal® digital pachymeter were larger than the measurements from the P3Dental™ software package. In this case there was no statistically significant difference (P=0.13).

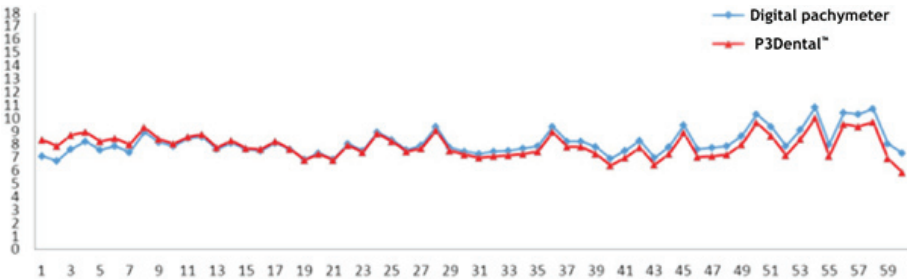

Figure 8. Distribution of left-side measurements.

Comparisons were also made between the results for the two types of equipment considering only measurements from the inferior or only from the superior areas of the sections. Table 4 lists descriptive statistics for measurements of the inferior regions taken with the Frankford Arsenal® digital pachymeter and using the P3Dental™ image software

for planning. The mean of the P3Dental™ measurements was 8.81mm, whereas the mean value for the measurements taken with the Frankford Arsenal® digital pachymeter was 8.38mm. Analysis of the results for the inferior regions (Figure 9) revealed forty cases in which the P3Dental™ measurement was larger. It can therefore be concluded that there were statistically significant differences (P=0.01) between the measurements with the two types of equipment.

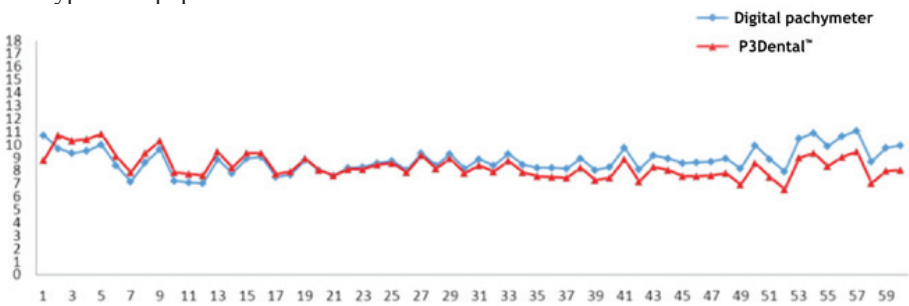

Figure 9. Distribution of measurements of the inferior region of the sections.

A comparison between measurements with the two types of equipment was also conducted for the results for the superior region of the sections only. Table 5 contains the descriptive analyses, showing that the mean with P3Dental™ software was 7.49 mm, and the mean with the Frankford Arsenal® digital pachymeter was 7.4 mm. The analysis of results for the superior region (Figure 10) detected thirty-one occurrences in which the larger measurement was the result of using P3Dental™ software.. In this case, no statistically significant difference (P=0.39) was detected between the measurements with the two types of equipment.

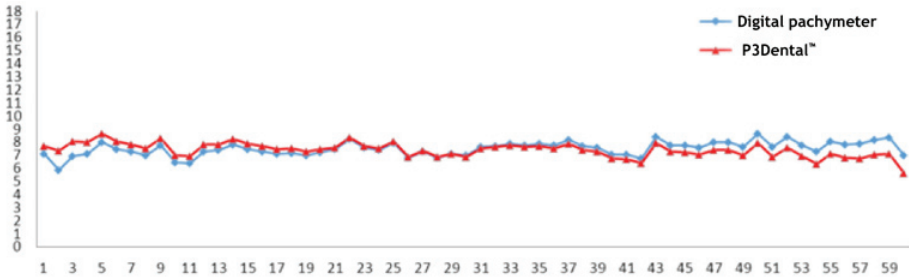

Figure 10. Distribution of measurements of the superior region of the sections.

DISCUSSION

Discrepancies between planned values and real values can be caused by many factors, including the image software used for planning, and they may or may not cause errors when defining the ideal positions of implants.

The objective of this study was to evaluate the reliability of planning with P3Dental™ software by comparison with real values measured using a digital pachymeter. The results show that there were statistically significant differences between the real measurements and the virtual measurements. Table 1 shows that assessment of all of the measurements made with P3Dental™ software in comparison with all measurements taken using the digital pachymeter revealed that the largest mean was for the virtual measurements (P3Dental™ software), which had mean ± standard deviation of 8.15 ± 1.01 mm, whereas the digital pachymeter had mean ± standard deviation of 7.89 ± 0.90 mm. Testing these values showed that the difference was significant (P=0.03) when the two types of equipment were compared and the difference between means was equivalent to 3.29%.

Table 1
Comparison of overall results for the Frankford Arsenal® digital pachymeter and P3Dental™ software.

Type of equipment	N	Minimum value (mm)	Maximum value (mm)	Mean ± standard deviation
Frankford Arsenal® digital pachymeter	120	5.62	10.83	7.89 ± 0.90mm
P3Dental™	120	5.86	11.08	8.15 ± 1.01mm

There are other studies in the literature with similar objectives, such as one study which reviewed scientific articles to assess the accuracy of systems for implant planning and found mean differences of 1.2 to 2 mm between real values and values planned on the planning software (7,16). Other studies of the accuracy of transference of measurements to the surgical field found that maximum discrepancies between virtual and real values in the longitudinal direction of the implants were from 1.1 mm to 1.6 mm (17-18). Another study, employing polyurethane mandibles into which dental implants were inserted, found discrepancies between the planned virtual values and the real positions of the implants, Measurements were taken at the apex, center and crown of the implant and analysis showed that vertical measurements differed by mean ± standard deviation of 1.39 ± 0.40 mm, 1.36 ± 0.41 mm and 1.38 ± 0.42 mm respectively and that these results were statistically significant (10). Although those studies used different methodology, the results reported are similar to those observed in this study, showing that distortion is expected, with a mean magnitude of around 1.46 mm.

When virtual and real measurements were analyzed for right and left side separately, the results were different for each side. Analysis of the right side alone (Table 2) found that the mean was larger for measurements with P3Dental™ software, with significant differences (P=0.01) between real and virtual values. Analysis of the left-side measurements alone (Table 3) detected that the larger mean was for measurements taken using the Frankford Arsenal® digital pachymeter, but, in contrast to the right side, there was no significant difference (P=0.13) between real and virtual values. When measurements were compared separately for the superior and inferior regions of the sections, in both cases means were larger using P3Dental™ software, but statistical

significance differed. There were significant differences (P=0.01) for the inferior region (Table 4), with a 5.1% variation between means, but there were no significant differences (P=0.39) for the superior region (Table 5), with a difference of 1.21% between means of real and virtual values.

Table 2
Comparison of right-side measurement results for the Frankford Arsenal® digital pachymeter and P3Dental™ software.

Type of equipment	N	Minimum value (mm)	Maximum value (mm)	Mean ± standard deviation
Frankford Arsenal® digital pachymeter	60	5.62	9.48	7.65 ± 0.78mm
P3Dental™	60	6.76	11.08	8.39 ± 1.06mm

Table 3
Comparison of left-side measurement results for the Frankford Arsenal® digital pachymeter and P3Dental™ software.

Type of equipment	N	Minimum value (mm)	Maximum value (mm)	Mean ± standard deviation
Frankford Arsenal® digital pachymeter	60	6.76	10.83	8.13 ± 0.96mm
P3Dental™	60	5.86	10.02	7.91 ± 0.90mm

Table 4
Measurements of the inferior regions of the sections with the Frankford Arsenal® digital pachymeter and P3Dental™ image software for planning.

Type of equipment	N	Minimum value (mm)	Maximum value (mm)	Mean ± standard deviation
Frankford Arsenal® digital pachymeter	60	6.60	10.83	8.38 ± 0.94mm
P3Dental™	60	7.05	11.08	8.81 ± 0.94mm

Table 5
Measurements of the superior regions of the sections with the Frankford Arsenal® digital pachymeter and P3Dental™ image software for planning.

Type of equipment	N	Minimum value (mm)	Maximum value (mm)	Mean ± standard deviation
Frankford Arsenal® digital pachymeter	60	5.62	8.63	7.40 ± 0.54mm
P3Dental™	60	5.86	8.65	7.49 ± 0.53mm

There are few explanations for this difference offered in the literature, but in one study that assessed the effect of positioning of the mandible on the accuracy of results obtained using computed tomography, it was shown that the position of the mandible with relation to the computed tomography can affect the precision of linear measurements. That

study suggested that in order to prevent distortions in the image and uncertain assessments as a consequence, it is necessary to perform computed tomography perpendicular to the ideal axis of the teeth or, in this case, the implants (8).

CONCLUSIONS

This study demonstrated statistically significant differences (P=0.01) between real values measured with the digital pachymeter and virtual values measured using P3Dental™ software which had mean ± standard deviation of 7.89 ± 0.90mm and 8.15 ± 1.01mm respectively. These variations were in agreement with results found in the literature. As such, dental surgeons must be aware that the technique for conducting guided surgery should be indicated and employed with care and with precise selection of cases, since small errors of use are cumulative, increasing the likelihood of distortion between the ideal (virtual) and final (real) positions of the implants.

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